

The Disappearance of the Red Supergiant Progenitor of Supernova 2008bk

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Massive stars end their lives in spectacular supernova explosions. Identifying the progenitor star is a test of stellar evolution and explosion models. Here we show that the progenitor star of the supernova SN 2008bk has now disappeared, which provides conclusive evidence that this was the death of a red supergiant star.

The progenitors of core-collapse supernovae (CCSNe) are massive bright stars, and thus can be directly detected in nearby galaxies if high quality images before the explosion are available. Using this technique the progenitor stars of a total of nine CCSNe have so far been identified; and their inferred masses all indicate that the minimum mass threshold for a star to explode as a CCSN is $8 \pm 1 M_{\odot}$ (*1*). However, we can be absolutely confident we have correctly identified the progenitor only when the star is confirmed to have disappeared by late time deep imaging

of its site of explosion. We have only witnessed the disappearance of the progenitors of four CCSNe (2,3,4), and present here such a confirmation for the nearby Type IIP SN 2008bk. We show that the progenitor star has disappeared in four bands, which is compelling evidence that the progenitor star's spectral type, luminosity and mass are well constrained and that the object identified was a single star.

SN 2008bk was discovered in the nearby spiral galaxy NGC 7793 on March 2008 and was classified as a Type II-P SN. Analysis of high-quality optical and near-infrared pre- and post-explosion images from the European Southern Observatory (ESO) Very Large Telescope (VLT) revealed a very red pre-explosion source coincident with the position of SN 2008bk (5). The colors and luminosity of the source were found consistent with it being a M4 red supergiant star with an initial mass of $8.5 \pm 1.0 M_{\odot}$ putting it at the low mass end of directly detected progenitors of Type II-P SNe which are the most common type of SN explosions in the Universe, by volume. With a detection in four different filters covering both optical and near-infrared wavelengths this is one of the best constrained SN progenitors observed, making its determined mass also one of the tightest constraints on the lower mass threshold for stars to explode as CCSNe.

We have re-imaged (supporting online text) the explosion site of SN 2008bk on 2010 September 16 using the ESO Faint Object Spectrograph and Camera (EFOSC2) with V , R , and I filters, and on 2010 October 29 using the SofI infrared spectrograph and imager with J , H and K_s filters, both on the ESO New Technology Telescope (NTT). Using differential astrometry, we matched the pre-explosion observations of SN 2008bk with our new images. We find no significant detection of a point source at the SN location in the same filters (I , J , H , and K_s) where the pre-explosion source was detected in the VLT images obtained before the SN explosion (Fig. 1). However, SN 2008bk was still marginally detected in the V and R filters.

The disappearance of the pre-explosion source identified at the position of SN 2008bk confirms it to be the progenitor and shows that it was a single massive star. This is compelling verification of stellar evolution theory that predicts core-collapse when massive single stars are red supergiants. The two best constrained and confirmed progenitors of type II-P SNe are for SN 2003gd (6,3) and SN 2008bk (5). These are both M0-M4 red supergiant stars with estimated initial masses at the lower end of the mass range considered theoretically possible to produce a core-collapse SN explosion.

References and Notes

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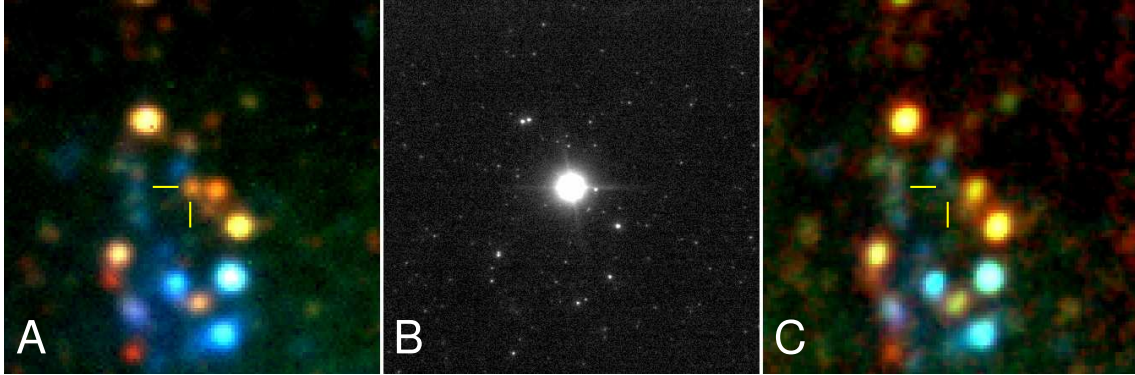


Fig. 1. The explosion site of SN 2008bk as observed with the ESO VLT and NTT (supporting online text). (A) Pre-explosion color-combined (V , I and K_s -bands) VLT image (2001 September 16 and 2005 October 17) showing a very red pre-explosion source coincident with the SN position. (B) post-explosion K_s -band adaptive optics VLT image (2008 May 19) showing the SN near the maximum light. (C) post-explosion late time color-combined (V , I and K_s -bands) NTT image (2010 September 16 and October 29) observed after the SN has faded away. The red supergiant progenitor star identified in Mattila et al. (5) is indicated in (A) but no point source is detected at its position in the late-time image (C).

Supporting Online Material for The Disappearance of the Red Supergiant Progenitor of Supernova 2008bk

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1 Supporting Online Text

SN 2008bk was discovered (S1) on 2008 March 25 and was spectroscopically classified (S2) as a Type II-P supernova (SN). The site of SN 2008bk has a wealth of predisccovery images available where a pre-explosion source was identified as a possible progenitor for the SN (S3,S4), and in (S5) it was precisely identified as the progenitor and shown to be a M4 red supergiant star with an initial mass of $8.5 \pm 1.0 M_{\odot}$.

The high quality pre-explosion imaging were available from the European Southern Observatory (ESO) Science Archive¹ (Table 1). The optical observations were taken with FORS1 and the near-infrared observations with ISAAC and HAWK-I on the ESO Very Large Telescope (VLT). To precisely identify the progenitor star we observed SN 2008bk on 2008 May 19 using the adaptive optics imager NACO on the VLT (program 081.D-0279, P.I.: S. Mattila). The reductions and calibration of these pre- and post-explosion observations are reported in (S5). The site of SN 2008bk was revisited on 2010 September 16 and October 29 when the SN was expected to have faded-away to confirm the disappearance of the progenitor (Table 1). This time the optical observations were taken with EFOSC2 and the near-infrared observations using SofI on the ESO New Technology Telescope (NTT) (program 184.D-1151, P.I.: S. Benetti). Both the optical and near-infrared images were reduced in a standard way in the image reduction and analysis facility (IRAF).

The late time post-explosion observations were aligned in IRAF with the pre-explosion images using geometric transformations including x and y shifts, and a common scale factor and rotation for x and y using centroid positions of point sources common between the frames. For example, in K_s -band fifteen point sources were used yielding a root mean square uncertainty of 35 milliarcsecond for the transformation. The comparison between the images revealed the source identified as the progenitor of SN 2008bk to have disappeared in the late-time post-explosion images in all the four bands where originally detected (I , J , H , and K_s). In these bands, the SN had already faded-away whereas it was still marginally detected in the late-time V and R band images. To better visualize the data all the images were scaled to a common pixel scale of $0.20'' \text{ pixel}^{-1}$ and the pre-explosion K_s image with the best seeing was convolved to match the point spread functions (PSF) of the pre-explosion I -band observation using the ISIS image subtraction software (S6). Both the pre- and post-explosion V , I , and K_s -band images were color-combined using the DS9 tool² and are shown in *Fig. 1*.

References and Notes

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¹<http://archive.eso.org/>

²<http://hea-www.harvard.edu/RD/ds9/>

Table 1: Pre- and post-explosion observations of the site of SN 2008bk.

Date (UT)	Telescope/ Instrument	Filter	Exp. Time (sec)	FWHM (arcsec)	resolution (arcsec/pixel)
Pre-explosion					
2001 Sept 16.0	VLT/FORS1	<i>B</i>	300	1.2	0.20
2001 Sept 16.0	VLT/FORS1	<i>V</i>	300	1.0	0.20
2001 Sept 16.0	VLT/FORS1	<i>I</i>	480	0.9	0.20
2005 Apr 21.6	VLT/ISAAC	<i>J</i>	17×60	0.5	0.148
2005 Oct 17.1	VLT/ISAAC	<i>K_s</i>	58×60	0.4	0.148
2007 Oct 16.1	VLT/HAWKI	<i>H</i>	2×60	0.8	0.1064
Post-explosion					
2008 May 19.4	VLT/NACO	<i>K_s</i>	20×60	0.1	0.027
Late time post-explosion					
2010 Sept 16.2	NTT/EFOSC2	<i>V</i>	8×120	0.8	0.24
2010 Sept 16.2	NTT/EFOSC2	<i>R</i>	5×120	0.9	0.24
2010 Sept 16.2	NTT/EFOSC2	<i>I</i>	4×120	1.1	0.24
2010 Oct 29.0	NTT/SOFI	<i>J</i>	29×60	1.5	0.288
2010 Oct 29.1	NTT/SOFI	<i>H</i>	30×60	1.2	0.288
2010 Oct 29.1	NTT/SOFI	<i>K_s</i>	30×60	1.2	0.288